

Sward Structure of Simple and Complex Mixtures of Temperate Forages

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ABSTRACT

Sward composition and structure influence herbage intake of grazing animals. We conducted a grazing study to examine how forage mixture complexity affected sward structure. Replicated 1-ha pastures (Hagerstown silt loam soil: fine, mixed, semiactive, mesic, Typic Hapludalf) were planted to either orchardgrass (*Dactylis glomerata* L.) and white clover (*Trifolium repens* L.) or a nine-species mixture [orchardgrass, tall fescue (*Festuca arundinacea* Schreb.), perennial ryegrass (*Lolium perenne* L.), Kentucky bluegrass (*Poa pratensis* L.), red clover (*Trifolium pratense* L.), birdsfoot trefoil (*Lotus corniculatus* L.), white clover, alfalfa (*Medicago sativa* L.), and chicory (*Cichorium intybus* L.)]. Pastures were stocked rotationally with lactating dairy cows (*Bos taurus*). Herbage mass, sward height, vertical structure, and nutritive value were measured pre- and postgrazing during four periods in each of 2002 and 2003. Pregrazing sward height was similar between the mixtures. Pregrazing herbage mass and sward bulk density were 30% less in the two-species mixture than the nine-species mixture in 2002 but similar in 2003. The nine-species mixture had more herbage dry matter in the upper sward layers than the two-species mixture. Bulk density of herbage dry matter increased and nutritive value decreased from the top to the bottom of both swards. Cattle grazed deeper into the two-species sward (18 cm) than the nine-species mixture (11 cm) in 2003; however, individual botanical components in the upper 25 cm of the canopy were removed similarly between treatments. We conclude that sward structure did not alter the pattern of herbage removal during grazing of simple or complex swards.

PASTURES often contain complex plant communities. In the northeastern USA, for example, species richness in pastures ranges from 18 to 53 species per 0.1 ha (Tracy and Sanderson, 2000). Plant species diversity affects ecosystem functions such as primary productivity and resistance to invasion (Fridley, 2001). Some suggest that managing species-diverse (complex) mixtures of forages is a low-input way of increasing herbage productivity in pastures (Tilman et al., 1999; Minns et al., 2001; Sanderson et al., 2004). Complex mixtures of forages yielded more herbage than simple grass-legume mixtures when compared in grazed small plots (Deak et al., 2004) or pastures (Sanderson et al., 2005).

Animal performance on pasture depends not only on herbage productivity, but also on how the grazing animal interacts with the sward through its ingestive behavior, including grazing time, bite rate, and bite size (Ungar, 1996; Gordon, 2000). Several structural characteristics

of the sward affect grazing animal ingestive behavior and ultimately affect grazed herbage intake (Hodgson, 1985). These vertical structural features include sward height, bulk density, and the distribution of leaves, stems, dead material, and plant species within the canopy (Gordon, 2000; Laca and Lemaire, 2000). Herbage intake by grazing animals increases asymptotically with sward height (Allden and Whittaker, 1970) and with the proportion of green leaf in the canopy (Chacon and Stobbs, 1976). Bulk density influences herbage intake mainly through bite size (Stobbs, 1973).

The vertical structure has been well described for homogeneous swards of temperate legumes and grasses such as perennial ryegrass and white clover. The upper sward layers consist mainly of live leaves, whereas the lower layers contain mostly stems, petioles, leaf sheaths, and dead material (Hodgson, 1985). As the sward ages, stem material becomes more uniformly distributed within the canopy. White clover leaves usually are arranged in a horizontal plane within the plant canopy, whereas grass leaves are more vertical. On these types of swards, cattle usually graze from the top of the canopy downward in successive layers with a minimum of selection (Hodgson, 1981).

Less is known, however, about the structure of complex mixtures of forages with contrasting morphology and how the structure affects grazing behavior. Because of differences among species in height, leaf and stem arrangement, and growth patterns, we would expect swards composed of a mixture of grasses, legumes, and forbs to be more complicated in vertical structure than a two-species grass-legume mixture. The differences in vertical structure between the two sward types would probably affect the ingestive behavior of grazing cattle because of the greater opportunity for selection among species within the complex mixture than in the grass-legume sward. For example, the ingestive behavior of grazing dairy cattle differed when grazed on swards of tropical grasses and legumes with contrasting height and morphology (Stobbs, 1973). On complex swards at high herbage allowance, cattle are vertically oriented in their grazing (Ungar, 1996).

Previously, we reported on how forage mixture complexity (two-, three-, six-, and nine-species mixtures) affected herbage yield and botanical composition (Sanderson et al., 2005) and herbage intake and milk production of dairy cows (Soder et al., 2006). Our objective in the current study was to determine how forage mixture complexity affected sward structure, including the vertical distribution of species. We compared a relatively simple mixture (orchardgrass-white clover) with a complex mixture of nine species that included grasses, legumes, and chicory.

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Abbreviations: CP, crude protein; DM, dry matter; IVTD, in vitro true digestibility; NDF, neutral detergent fiber.

MATERIALS AND METHODS

We conducted the research at the Dairy Cattle Research and Education Center of the Pennsylvania State University in University Park. We compared two forage mixtures in 1-ha pastures: (i) orchardgrass ('Baridana') and white clover ('Will'); and (ii) orchardgrass, tall fescue ('Barolex'), perennial ryegrass ('BG-34'), Kentucky bluegrass ('Sidekick'), red clover ('Start'), birdsfoot trefoil ('Norcen'), white clover, alfalfa ('Amerigraze'), and chicory ('Puna'). The seeding rate for orchardgrass was 17 kg ha⁻¹ and 8 kg ha⁻¹ for white clover in the two-species mixture. In the nine-species mixture, all species were seeded at 6 kg ha⁻¹. The two-species mixture is commonly used in the northeastern USA. The nine-species mixture was formulated to have redundancy in the grass and legume functional groups. Chicory is the only commercially available forb used in forage production, thus we did not use multiple forb species. The pastures were no-till planted in August 2001. The experimental design was a randomized complete block with two replicates (pastures) of each mixture.

Soil at the site is a Hagerstown silt loam. Soil tests (to a 15-cm depth) in 2001 indicated a pH of 6.5, 220 kg ha⁻¹ available P, and 210 kg ha⁻¹ available K; thus no lime, P, or K was required. We did not apply fertilizer N; instead, we relied on N₂ fixation by the legumes.

The pastures were stocked rotationally with lactating Holstein cows from April through August in 2002 and 2003. Five cows grazed each treatment. At the start of the trial, the cows were of similar body weight (648 kg), milk yield (47 kg d⁻¹), lactation (3), and days in milk (109). The target intake rate was 12 kg d⁻¹ of herbage dry matter. The daily herbage allocation was 25 kg dry matter cow⁻¹. Cows were confined to a fresh area of pasture (one-half of the daily herbage allocation) after each milking, which took place each morning at 0500h and afternoon at 1700h. The amount of herbage provided per cow was equalized among treatments twice weekly by using temporary electric fencing to adjust the area allotted for grazing. Cows were fed a maize (*Zea mays* L.)-based supplement (1 kg per 4 kg milk, 9.2 kg d⁻¹ maximum) in two equal feedings after milking. The experiment was conducted under the approval of the Pennsylvania State University Animal Care and Use committee.

Because of the amount of herbage allocated for the lactating dairy cows, a large amount of herbage remained after grazing in some periods. Biosecurity rules at the Pennsylvania State University precluded the use of additional dry cows or heifers in rotation with the lactating cows to clean up residual forage. Therefore, if necessary, pastures were clipped to a 10-cm stubble height after grazing.

Pregrazing herbage mass was measured twice each week during the grazing season with a calibrated rising plate meter (Jenn Quip, Feilding, New Zealand). Thirty plate readings were taken in each pasture on each measurement date. The plate meter was calibrated by clipping herbage in 24 to 30 quadrats (0.1 m²) to a 1-cm stubble height on three transects of 8 to 10 quadrats each. Twenty rising plate meter readings were taken on the same transects. Transect means of clipped herbage mass were regressed on transect means of plate meter readings for calibration. We developed a single calibration for all pasture mixture treatments within each year. The calibration equation for 2002 was herbage mass (kg DM [dry matter] ha⁻¹) = 353 + 84.5(rising plate reading), $r^2 = 0.82$, root error mean square = 318 kg DM ha⁻¹, $n = 78$. The equation for 2003 was herbage mass = -30 + 90.6(rising plate reading), $r^2 = 0.85$, root error mean square = 295 kg DM ha⁻¹, $n = 80$.

Postgrazing herbage mass was measured twice weekly during the grazing season by clipping 12 to 20 0.1-m² quadrats to a 1-cm stubble height on two transects of 8 to 10 quadrats each. Post-

grazing clips were taken within 18 h after grazing. We did not use the rising plate meter for post-grazing measurements because we could not obtain reliable calibrations. All clipped herbage samples (pre- and postgrazing) were dried at 55°C for 48 h.

We determined the structure of the sward in the four pastures during 13–17 May, 10–14 June, 24–28 June and 15–19 July 2002. The 2003 sampling dates were 12–15 May, 2–6 June, 20 June–3 July, and 21–25 July. These sampling times occurred during four 3-wk periods during which herbage intake and milk production were measured by others (Soder et al., 2006). Sward height was measured with a ruler at 20 to 30 points in each pasture before grazing. In 2002, the heights were taken at the natural position (unextended) of vegetation in the sward, whereas in 2003 extended plant heights were measured. Post-grazing height was measured in 2003 but not in 2002.

We determined the vertical distribution of dry matter within the sward canopy according to Barthram et al. (2000). We clamped a section of the sward (one seeded row) between two 5-cm-high by 50-cm-long boards and cut the herbage at ground level with a hand shears. Four of these clips were taken along each of two transects in each pasture before and after grazing in each of 2 d. Thus, we clipped 16 sward areas before and after grazing in each pasture during each sampling week. We marked the clipped area before grazing so that we could take the post-grazing sample nearby and avoided areas refused by the cows.

The sward sample was kept clamped and transported intact to the laboratory, where it was turned on edge and cut into six layers: 0–5, 5–12, 12–19, 19–26, 26–33, and >33 cm above the soil surface. Each layer was hand separated into grass, legume, chicory, weed, and dead material. The plant material was dried at 55°C for 48 h and weighed. We calculated a summary statistic describing the mean vertical distribution of herbage dry matter among the canopy layers. Barthram et al. (2000) termed this the "center of gravity" of herbage in the canopy. The equation used to calculate the center of gravity was $\sum[(\text{bulk density} \times \text{midpoint height of layer})/\text{total bulk density of all layers}]$ (Barthram et al., 2000).

Components were composited into one sample for each pasture in each sampling period pre- and postgrazing. Forage samples were analyzed for neutral detergent fiber (NDF), in vitro true digestibility (IVTD, 48-h fermentation), and crude protein (CP) by a commercial laboratory (DairyOne, Ithaca, NY). Several samples were lost in 2002, resulting in an incomplete dataset, thus we do not report the 2002 data. Detergent fiber and IVTD procedures were according to Van Soest and Robertson (1980). Digestible NDF was calculated from NDF and IVTD values. Nitrogen was determined by the Dumas combustion method (Association of Official Analytical Chemists, 1990) and CP calculated as 6.25(N).

Botanical composition of the pastures was measured once in each of the four sampling weeks in each year. At each sampling, total herbage in 10 quadrats (0.03 m²) was clipped to a 1-cm stubble in each pasture. The bulked herbage was hand separated into dead material, sown forage species, and unsown forbs and grasses. We did not sort to the species level for the unsown component. The herbage samples were dried at 55°C for 48 h, weighed, and the proportion of each species or component calculated.

Sward structure data were analyzed as a randomized complete block design with the mixed models procedure in SAS (Littell et al., 1996). Treatments were considered fixed effects and blocks were random. Years were analyzed separately. Botanical composition data for each period within years were analyzed as repeated measures in a randomized complete block design. Periods were considered fixed effects and blocks were random. In both analyses, a compound symmetry covariance structure best fit the data. Denominator degrees of

Table 1. Sward characteristics of two pasture mixtures during 2002 and 2003 at University Park, PA. Data are least squares means of four sampling periods.

Mixture	Sward height†			Grazing depth‡	Pregrazing herbage mass		Postgrazing herbage mass		Pregrazing bulk density	
	Pregrazing		Postgrazing							
	2002	2003	2003		2002	2003	2002	2003	2002	2003
	cm				kg green dry matter ha ⁻¹				kg green dry matter m ⁻³	
Nine species	32	41	29b§	11b	2360b	2560	1338b	1496	0.76b	0.63
Two species	31	44	26a	18a	1650a	2250	850a	1148	0.55a	0.51
SE¶	1.9	2.4	2.1	1.9	213	257	79	119	0.04	0.08

† Sward height in 2002 was unextended shoot height, whereas in 2003 it was extended shoot height.

‡ Grazing depth = pregrazing – postgrazing height.

§ Means with different letters within columns differ at $P < 0.05$.

¶ SE = standard error.

freedom were calculated with the Kenward-Rogers option in SAS. Statistical significance was declared at the $P < 0.05$ level.

RESULTS

Sward Height, Green Herbage Mass, and Botanical Composition

Pregrazing sward heights were similar between the treatments in each year (Table 1). The postgrazing sward height was lower and, as a result, the grazing depth was greater for the two-species mixture than the nine-species mixture in 2003. Sward heights were greater in 2003 than in 2002 partly because of the different methods of measurement in each year.

Pre- and postgrazing herbage mass was greater for the nine-species mixture than for the two-species mixture averaged for sampling periods in 2002 (Table 1). The mixtures did not differ in pre- or postgrazing herbage mass in 2003. There was a period \times mixture interaction for pregrazing herbage mass in 2002 caused by an increase in herbage mass for the nine-species mixture at Period 4, whereas herbage mass of the two-species mixture did not change (data not shown). In 2003, pregrazing herbage mass for both mixtures decreased during the measurement periods (data not shown). Because of differences between the two mixtures in pregrazing herbage mass in 2002, the sward bulk density was greater for the nine-species mixture than the two-species mixture.

The two-species mixture had a larger proportion of sown grasses and a lower proportion of legumes than the nine-species mixture (Table 2). White clover and red clover accounted for nearly all of the legume component of the nine-species mixture in both years. Chicory contributed $<30\%$ of the dry matter in the nine-species mixture. The proportion of nonsown species (including weeds) was greater in the two-species mixture than the nine-species mixture in both years.

Vertical Structure of the Sward

There was no mixture \times period interaction for the center-of-gravity data with the exception of dead material in 2002 and total herbage in 2003. Therefore, data for the bulk density of plant material in the sward layers are presented as an average of the four periods for each year in Table 3 and Fig. 1 to 4. In both years, more of the total herbage dry matter was distributed higher in the canopy (a higher center of gravity) of the nine-species

mixture than in the two-species mixture. The legume component in the nine-species mixture had a higher center of gravity pre- and postgrazing than in the two-species mixture averaged across sampling periods. There was no effect of mixture treatment on the vertical distribution of grass within the sward (Table 3).

The center of gravity for nearly all components was lower postgrazing than pregrazing (Table 3, Fig. 1–4). The exception was dead material, which was concentrated in the basal 6 cm both pre- and postgrazing (Table 3). In 2002, the dry matter of nonsown species was distributed higher in the canopy in the nine-species mixture than in the two-species sward, whereas in 2003, the distribution was the same between the mixtures.

The pattern of vertical dry matter distribution was an increase in bulk density from the top to the bottom of the sward both pre- and postgrazing (Fig. 1–4). The top two to three layers of herbage were nearly completely removed by grazing cattle in each year. Very little grass or chicory dry matter in the bottom 0- to 5-cm layer was removed by grazing cattle. Legumes, however, were grazed in the lowest layer, predominantly in the two-species mixture.

Nutritive Value of Sward Components

The nutritive value of the sward botanical components was lowest at the base of the canopy in most instances

Table 2. Pregrazing botanical composition of two pasture mixtures during 2002 and 2003 at University Park, PA. Data are least-squares means of four sampling periods.

Botanical component	2002			2003		
	Nine species	Two species	SE†	Nine species	Two species	SE
	% of dry matter					
White clover	18b	28a‡	6.0	48	32	13.7
Orchardgrass	4b	35a	2.9	10b	46a	7.4
Nonsown species	5b	28a	3.6	3b	11a	4.0
Dead	12	9	3.2	4b	11a	3.0
Chicory	28		5.0	14		6.0
Red clover	20		5.6	11		7.2
Tall fescue	4		3.1	2		3.0
Alfalfa	3		2.4	2		0.6
Birdsfoot trefoil	0.4		0.2	2		1.3
Perennial ryegrass	5		2.9	3		2.5
Kentucky bluegrass	0.5		0.3	0.3		0.3

† SE = standard error.

‡ Means within rows and years with different letters differ at $P < 0.05$.

Table 3. Pre- and postgrazing center of gravity (mean vertical distribution) of sward components in two pasture mixtures during 2002 and 2003 at University Park, PA. Data are least squares means of four sampling periods.

Mixture	2002		2003	
	Pregrazing	Postgrazing	Pregrazing	Postgrazing
cm				
Total herbage				
Nine species	11.7a†	6.2a	9.8a	6.2a
Two species	8.4b	4.4b	8.3b	5.3b
SE‡	0.50	0.48	0.56	0.50
Grass				
Nine species	9.5	5.2	10.7	5.8
Two species	9.8	4.8	9.8	6.2
SE	1.00	0.82	1.35	1.34
Legume				
Nine species	12.3a	6.4a	9.0a	5.7a
Two species	10.1b	4.9b	7.3b	4.4b
SE	0.61	0.45	0.40	0.59
Chicory				
Nine species	13.8	7.1	12.0	8.2
SE	1.25	2.00	1.20	0.97
Nonsown species				
Nine species	11.8a	5.4	7.4	4.9
Two species	8.1b	5.0	7.0	4.5
SE	1.20	0.68	0.88	1.29
Dead matter				
Nine species	4.3	3.6	3.4	4.0
Two species	3.9	3.4	5.2	3.0
SE	0.52	0.25	2.66	0.78

† Means within columns and components with different letters differ at $P < 0.05$.

‡ SE = standard error.

(Table 4). Crude protein decreased from the top to the bottom of the sward in both mixtures pre- and postgrazing. Concentrations of NDF were greater at the bottom

of the sward than in the upper layers for the chicory and legume components. The grass component of the nine-species sward did not change much in NDF within the sward. The pattern of digestible NDF among the sward layers was not as clear cut. In some instances there did not seem to be a pattern to the fluctuations in digestible NDF among the sward layers (e.g., the legume component), whereas the grass component clearly decreased in digestible NDF with depth in the sward.

DISCUSSION

We used pastures seeded to different mixtures of forage species to generate swards with differences in structure. Our hypothesis was that a complex mixture of forage species would have a different vertical structure than a simple mixture. We successfully established two mixtures that differed in a number of key sward structural attributes. The mixtures differed in herbage mass and bulk density in 1 yr and the botanical composition and vertical distribution of dry matter within the swards differed in both years. Pregrazing sward height was similar between the mixtures; however, postgrazing sward height was lower and cattle grazed deeper into the two-species mixture than the nine-species mixture. The botanical composition of the mixtures differed greatly and the distribution of the botanical components within the swards differed (Table 2, Fig. 1–4). Detailed changes in botanical composition and herbage yield for the grazing season are reported in Sanderson et al. (2005). The two-species sward had a lower herbage mass and bulk density pregrazing than the nine-species mixture in 2002 (Table 1). Seasonal herbage yield was greater for the complex forage mixtures than the orchardgrass–white clover mixtures in 2002 (a dry year) than in 2003 (a wet year) (Sanderson et al., 2005).

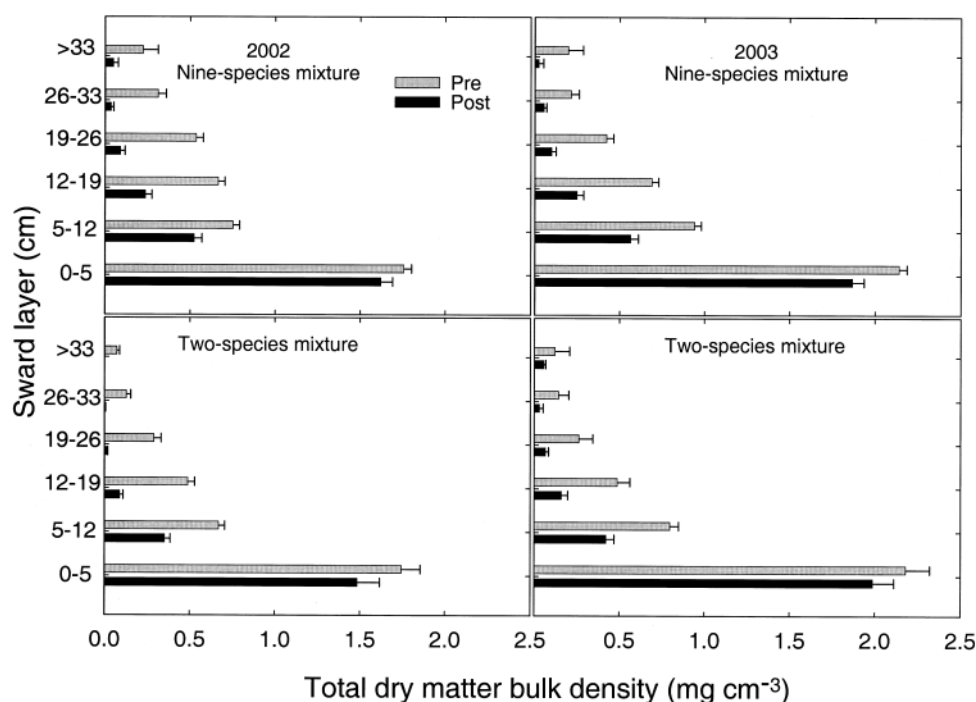


Fig. 1. Pre- and postgrazing vertical distribution of herbage bulk density in two pasture mixtures during 2002 and 2003 at University Park, PA. The 0- to 5-cm layer is the base of the sward. Data are least squares means of four sampling periods. Error bars indicate one standard error.

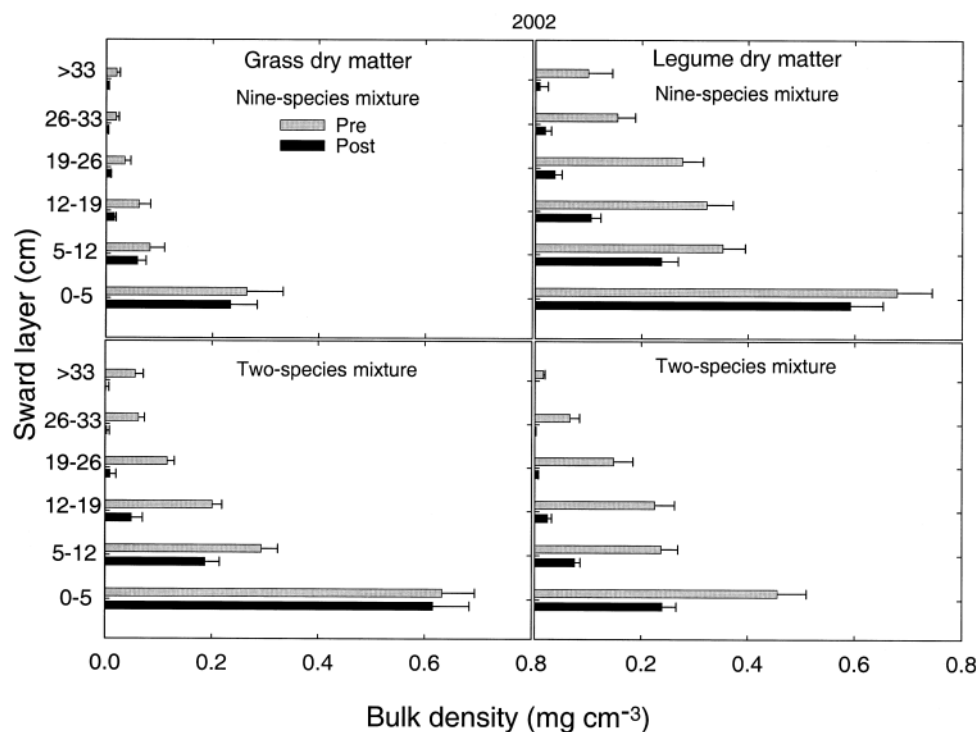


Fig. 2. Pre- and postgrazing vertical distribution of grass and legume bulk density in two pasture mixtures during 2002 at University Park, PA. The 0- to 5-cm layer is the base of the sward. Data are least squares means of four sampling periods. Error bars indicate one standard error.

The bulk density increased and the nutritive value of both swards decreased from the top to the bottom of the canopy as observed by others (Stobbs, 1973; Ungar and Ravid, 1999; Barthram et al., 2000). The nine-species mixture had more herbage dry matter in the upper por-

tion of the sward, contributed mainly by the legume and chicory components. Red clover is a tall legume with leaves on an erect stem, whereas white clover is low growing, with leaves borne on petioles originating from the stolon. Orchardgrass was used in both mixtures, so

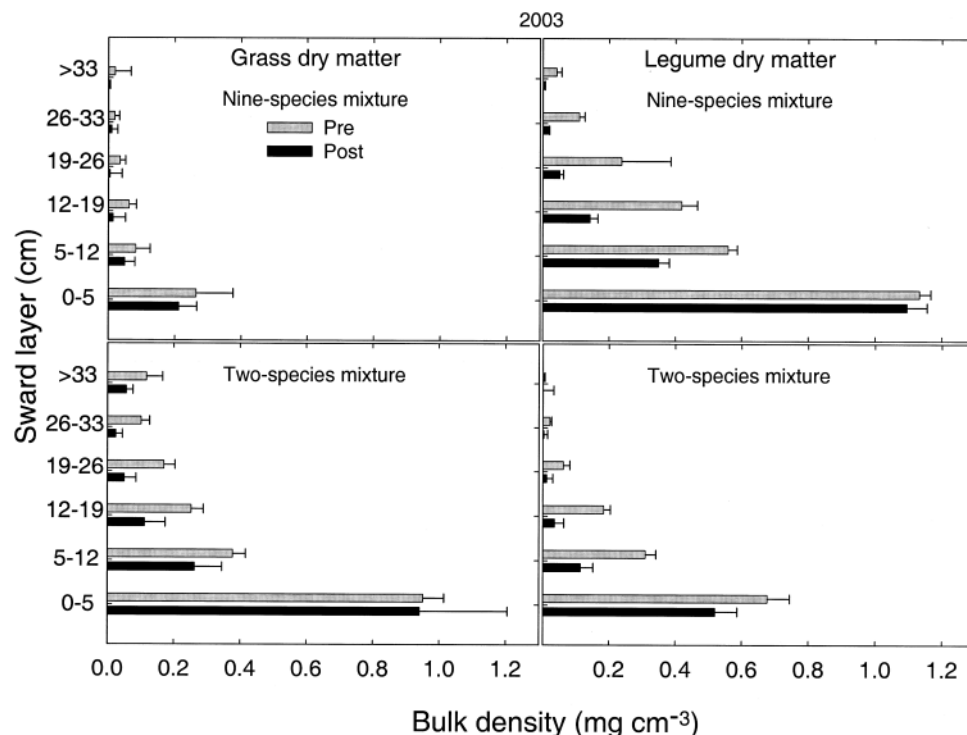


Fig. 3. Pre- and postgrazing vertical distribution of grass and legume bulk density in two pasture mixtures during 2003 at University Park, PA. The 0- to 5-cm layer is the base of the sward. Data are least squares means of four sampling periods. Error bars indicate one standard error.

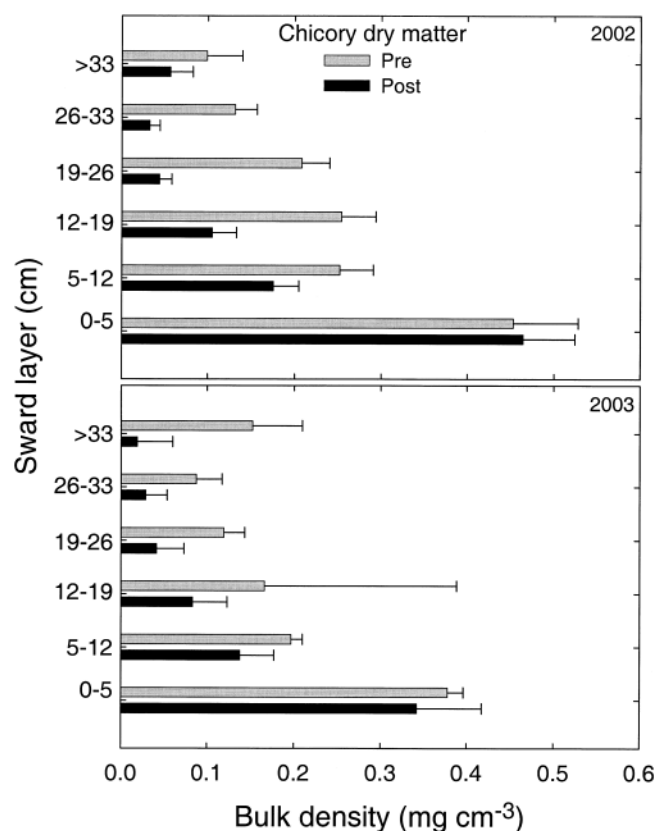


Fig. 4. Pre- and postgrazing vertical distribution of chicory bulk density in two pasture mixtures during 2002 and 2003 at University Park, PA. The 0- to 5-cm layer is the base of the sward. Data are least squares means of four sampling periods. Error bars indicate one standard error.

similarity in the distribution of grass dry matter within the sward would be expected. The lower distribution of dry matter within the two-species sward compared with the nine-species sward would account for the greater grazing depth for the two-species sward in 2003 despite a similar pregrazing sward height in both mixtures.

Despite the differences in sward structure, grazed herbage intake averaged 12.9 and 11.1 kg d⁻¹ and milk production averaged 34.1 and 34.3 kg cow⁻¹ d⁻¹ for the two- and nine-species mixtures, respectively, with no differences among treatments (Soder et al., 2006). Thus, the differences between treatments in sward structure did not appear to affect intake or animal performance.

In swards of temperate forages, herbage intake frequently increases with greater sward bulk density (Hodgson, 1985). Sward height, however, interacts with herbage mass in influencing intake such that taller swards of lower herbage mass sometimes support high herbage intake (Black and Kenney, 1984). Because of the greater pregrazing herbage mass of the nine-species sward in 2002 compared with the two-species sward, we might have expected greater herbage intake on the more complex sward. The cattle may have compensated for the differences in herbage mass by grazing deeper into the two-species sward, as indicated by the greater grazing depth in 2003 (Table 1). Barrett et al. (2003) reported that herbage intake and bite mass of grazing dairy cattle did not differ on artificially constructed ryegrass swards that varied in height, herbage mass, and bulk density because the cattle grazed deeper into some swards than others.

The top two to three layers (19–33 cm) of both swards were nearly completely removed by the grazing cattle and it seems that the swards were depleted similarly between the treatments throughout the upper 25 cm of

Table 4. Pre- and postgrazing nutritive value among vertical layers of sward components in two pasture mixtures during 2003 at University Park, PA. Data are least squares means of four sampling periods.

Sward layer cm	Chicory		Legume				Grass			
	Nine species		Nine species		Two species		Nine species		Two species	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Crude protein, g kg⁻¹ dry matter										
>33	265	214	311		363		268		266	212
26–33	277	252	347	306	371	301	284	145	267	211
19–26	275	249	335	307	351	303	256	222	242	201
12–19	249	222	322	282	324	287	237	209	220	196
5–12	220	200	283	256	294	273	225	200	187	175
0–5	163	167	237	227	248	242	196	194	147	144
SE	9.6	9.1	6.8	6.4	8.1	7.0	7.6	6.6	9.7	7.4
Neutral detergent fiber, g kg⁻¹ dry matter										
>33	277	302	189		167		602		556	661
26–33	261	242	205	216	186	200	589	709	586	646
19–26	238	280	211	248	195	258	614		593	623
12–19	262	316	238	266	212	255	616	631	602	643
5–12	303	327	273	314	254	283	617	602	637	648
0–5	469	401	345	359	318	330	635	625	660	678
SE	19.5	14.9	9.3	10.8	9.4	10.9	6.0	8.3	7.4	6.9
Digestible neutral detergent fiber, g kg⁻¹ neutral detergent fiber										
>33	753	725	688		860		768		786	657
26–33	742	602	630	778	710	670	767	650	744	785
19–26	727	740	654	669	729	813	754		749	668
12–19	697	661	709	645	775	687	676	627	711	663
5–12	720	642	609	684	739	690	670	580	659	634
0–5	663	598	674	649	700	685	639	604	636	658
SE	20.7	20.6	19.4	18.8	23.4	26.2	19.1	33.0	18.6	21.2

the canopy. This would indicate that the cattle grazed both swards as in the horizon-based model (Coleman et al., 1989; Ungar, 1996) and were not vertically oriented in their grazing behavior. The nutritive value of the upper canopy was relatively high and similar between the swards, thus cattle probably ingested herbage in the same proportions as it was encountered within the sward. We allotted enough pasture area to provide 25 kg of herbage dry matter per cow, moved cows to fresh pasture twice daily, and fed a concentrate supplement. Sward structure effects on herbage intake may be more evident at greater levels of herbage allowance, under different grazing management, or with unsupplemented cows.

CONCLUSIONS

Complex swards of grasses, legumes, and chicory differed from simple grass-legume swards in sward structural attributes. The differences in structural attributes, however, did not affect the pattern of herbage component removal during grazing nor did the differences affect herbage intake or milk production of Holstein cows at the level of herbage allocated in this study. We conclude that, at equivalent herbage mass and nutritive value, differences in sward structure caused by differences in botanical composition of temperate swards do not alter the patterns of herbage removal during dairy cattle grazing of simple or complex swards of temperate forages.

REFERENCES

- Allden, W.G., and I.A. McD. Whittaker. 1970. The determinants of herbage intake by grazing sheep: The interrelationship of factors influencing herbage intake and availability. *Aust. J. Agric. Res.* 21: 755-766.
- Association of Official Analytical Chemists. 1990. Method 990.03, Crude protein in animal feed. p. 18-19. *In* Official methods of analysis. 19th ed. AOAC, Arlington, VA.
- Barrett, P.D., D.A. McGiloway, A.S. Laidlaw, and C.S. Mayne. 2003. The effect of sward structure as influenced by ryegrass genotype on bite dimensions and short-term intake rate by dairy cows. *Grass Forage Sci.* 58:2-11.
- Barthram, G.T., D.A. Elston, and G.R. Bolton. 2000. A comparison of three methods for measuring the vertical distribution of herbage mass in grassland. *Grass Forage Sci.* 55:193-200.
- Black, J.L., and P.A. Kenney. 1984. Factors affecting diet selection by sheep: II. Effects of height and density of pasture. *Aust. J. Agric. Res.* 35:565-578.
- Chacon, E., and T.H. Stobbs. 1976. Influence of progressive defoliation of a grass sward on the eating behaviour of cattle. *Aust. J. Agric. Res.* 27:709-727.
- Coleman, S.W., T.D.A. Forbes, and J.W. Stuth. 1989. Measurements of the plant-animal interface in grazing research. p. 37-51. *In* G.C. Marten (ed.) *Grazing research: Design, methodology, and analysis*. CSSA Spec. Publ. 16. CSSA, Madison, WI.
- Deak, A., M.H. Hall, and M.A. Sanderson. 2004. Forage production and forage mixture complexity. *Proc. Am. Forage Grassl. Council* 13:220-224.
- Fridley, J.D. 2001. The influence of species diversity on ecosystem productivity: How, where, why? *Oikos* 93:514-526.
- Gordon, I.J. 2000. Plant-animal interactions in complex plant communities: From mechanism to modeling. p. 191-208. *In* G. Lemaire et al. (ed.) *Grassland ecophysiology and grazing ecology*. CABI Publ., New York.
- Hodgson, J. 1981. Variations in the surface characteristics of the sward and the short-term rate of herbage intake by calves and lambs. *Grass Forage Sci.* 36:49-57.
- Hodgson, J. 1985. The control of herbage intake in the grazing ruminant. *Proc. Nutr. Soc.* 44:339-346.
- Laca, E.A., and G. Lemaire. 2000. Measuring sward structure. p. 103-121. *In* L. t'Mannetje and R.M. Jones (ed.) *Field and laboratory methods for grassland and animal production research*. CABI Publ., New York.
- Littell, R.C., G.A. Milliken, W.W. Stroup, and R.D. Wolfinger. 1996. SAS system for mixed models. SAS Inst., Cary, NC.
- Minns, A., J. Finn, A. Hector, M. Caldeira, J. Joshi, C. Palmberg, B. Schmid, M. Scherer-Lorenzen, E. Spehn, and A. Troubis. 2001. The functioning of European grassland ecosystems: Potential benefits of biodiversity to agriculture. *Outlook Agric.* 30:179-185.
- Sanderson, M.A., R.H. Skinner, D.J. Barker, G.R. Edwards, B.F. Tracy, and D.A. Wedin. 2004. Plant species diversity and management of temperate forage and grazing land ecosystems. *Crop Sci.* 44:1132-1144.
- Sanderson, M.A., K.J. Soder, L.D. Muller, K.D. Klement, R.H. Skinner, and S.C. Goslee. 2005. Forage mixture productivity and botanical composition in pastures grazed by dairy cattle. *Agron. J.* 97:1465-1471.
- Soder, K.J., M.A. Sanderson, J.L. Stack, and L.D. Muller. 2006. Intake and performance of lactating cows grazing diverse forage mixtures during two grazing seasons. *J. Dairy Sci.* 89: (in press).
- Stobbs, T.H. 1973. The effect of plant structure on the intake of tropical pastures: I. Variation in the bite size of grazing cattle. *Aust. J. Agric. Res.* 24:809-819.
- Tilman, G.D., D.N. Duvick, S.B. Brush, R.J. Cook, G.C. Daily, G.M. Heal, S. Naeem, and D.R. Notter. 1999. Benefits of biodiversity. Task Force Rep. 133. Council for Agric. Sci. and Technol., Ames, IA.
- Tracy, B.F., and M.A. Sanderson. 2000. Patterns of plant species richness in pasturelands of the Northeast United States. *Plant Ecol.* 149:169-180.
- Ungar, E.D. 1996. Ingestive behaviour. p. 185-218. *In* J. Hodgson and A.W. Illius (ed.) *The ecology and management of grazing systems*. CABI Publ., New York.
- Ungar, E.D., and N. Ravid. 1999. Bite horizons and dimensions for cattle grazing herbage to high levels of depletion. *Grass Forage Sci.* 54:357-364.
- Van Soest, P.J., and J.B. Robertson. 1980. Systems of analysis for evaluating fibrous feeds. p. 49-60. *In* W.J. Pigden et al. (ed.) *Standardization of analytical methodology for feeds*. Proc. Int. Workshop, Ottawa, ON. 12-14 Mar. 1979. Rep. IRDC-134e. Int. Dev. Res. Center, Ottawa, ON, Canada and Unipub, New York.